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AN EXPANSION PLAN FOR THE 60 HZ POWER DISTRIBUTION SYSTEM AT KSC: LC-39 SUBSTATIONS LOAD ALLOCATION PLAN

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ABSTRACT

The increasing load density in the LC-39 area of Kennedy Space Center (KSC) can be met by either modifying the existing substation and increasing its capacity or by planning an additional new substation. This report provides evidence that the later approach is more economic, enhances the system reliability and would produce more satisfactory performance indices.

The proposed substation is optimally located based on network theory. A load reallocation plan which minimizes investment cost and power losses and meets other desirable system features is drafted. The report should be useful to the system designer and can be a useful guideline to future facility planners.

SUMMARY

This report compares the relative investment costs of expanding the C-5 substation or building a new substation to meet the power need due to increasing load density in the LC-39 area of Kennedy Space Center. In addition to more intensive labor demand, the distribution cost was determined to be higher for the C-5 expansion alternative. Similarly, this alternative suffers more power losses than the new substation approach. For these reasons and for other heuristic reasons the report recommends the building of an additional substation to meet the electric power need and projected need at LC-39 area distribution system.

Using minimum path algorithm the report suggests an optimal location for the proposed substation. A load allocation plan based on simple network theory is then used to reallocate some of the loads to the new substation. The plan suggested in this report would result in minimum investment cost and minimum system losses. Most importantly, the plan will enhance system reliability and meet desirable system performance characteristics.

The thrust of this research is to determine an optimal location for a proposed substation and based on this to evaluate the two alternative means of meeting the increasing load density. The process is based on data which contain uncertainties and thus results should be seen as a guide not a design of the system. The location of the proposed substation is determined by classical methods with environmental and social constraints taken into consideration. Also considered is an economic availability of power to future facilities.

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II. INTRODUCTION

2.1 Statement of Problem

The load demand in the Kennedy Space Center (KSC) power system has been increasing continuously since its inception twenty-five years ago. This increase has become more rapid in recent years due to increased frequency of vehicle launches and associated activities. A rather misleading average shows a predicted load growth of about 1.5 MVA per year. To keep up with this ever-increasing load density, effective expansion plans for the distribution systems are essential. Two alternative means to ensure no loss of load due to low installed capacity are: (a) to expand (increase) the capacity of the existing substations or, (b) to build new substations.

An essential part of the expansion planning is to determine which of the two alternatives should be implemented. This decision should be based on sound principles rather than be made arbitrarily. The criteria for determining which alternative should be adopted are investment and construction cost, power loss, reliability, and system performance indices, such as voltage regulation, etc. In addition to the above quantifiable measures, one also needs to look at other matters which are not easily quantifiable, such as long term economic and technical considerations, expected area of future (long term) expansion, and environmental and social constraints.

The system under study is the LC-39 area distribution system. Presently, it is supplied from a 45 MVA substation consisting of four 10 MVA main transformers and two 2.5 MVA transformers. Though the demand is fast approaching the capacity, several new facilities have been planned for the area in the next few years, thus creating a need for capacity expansion. The proposed facilities are mostly concentrated in the area between the VAB and Swartz Road and bounded by Contractors Road to the west. This study is based on the proposed load and the capacity-demand conditions of the feeders which presently supply electric power to the sub-area. The study shows that the winning alternative is building of a new substation which should be located in the area with high density of projected load growth. Based on this decision, a load reallocation plan between C-5 substation and the proposed substation is suggested.

2.2 Description of the Study System

Only a subsection of the LC-39 area of Kennedy Space Center is affected by the load allocation scheme. This area is bounded to the west by Contractors Road and lies between VAB and Swartz Road. The real estate in this area suffers considerable discontinuities due to patches of wetland. Several facilities have been planned for the area in the next few years and are sited at buildable columns of the real estate. None-the-less, there is still ample room for growth in the southeast portion of this sub-area. To the south of Swartz Road, adjoining the industrial area, lies substantial real estate for possible future expansion. This area, however, has high percentage of wetland. A diagram of the area affected by our study showing the facilities, the proposed facilities, the wetland patches and other geographic conditions is shown in Figure 1.

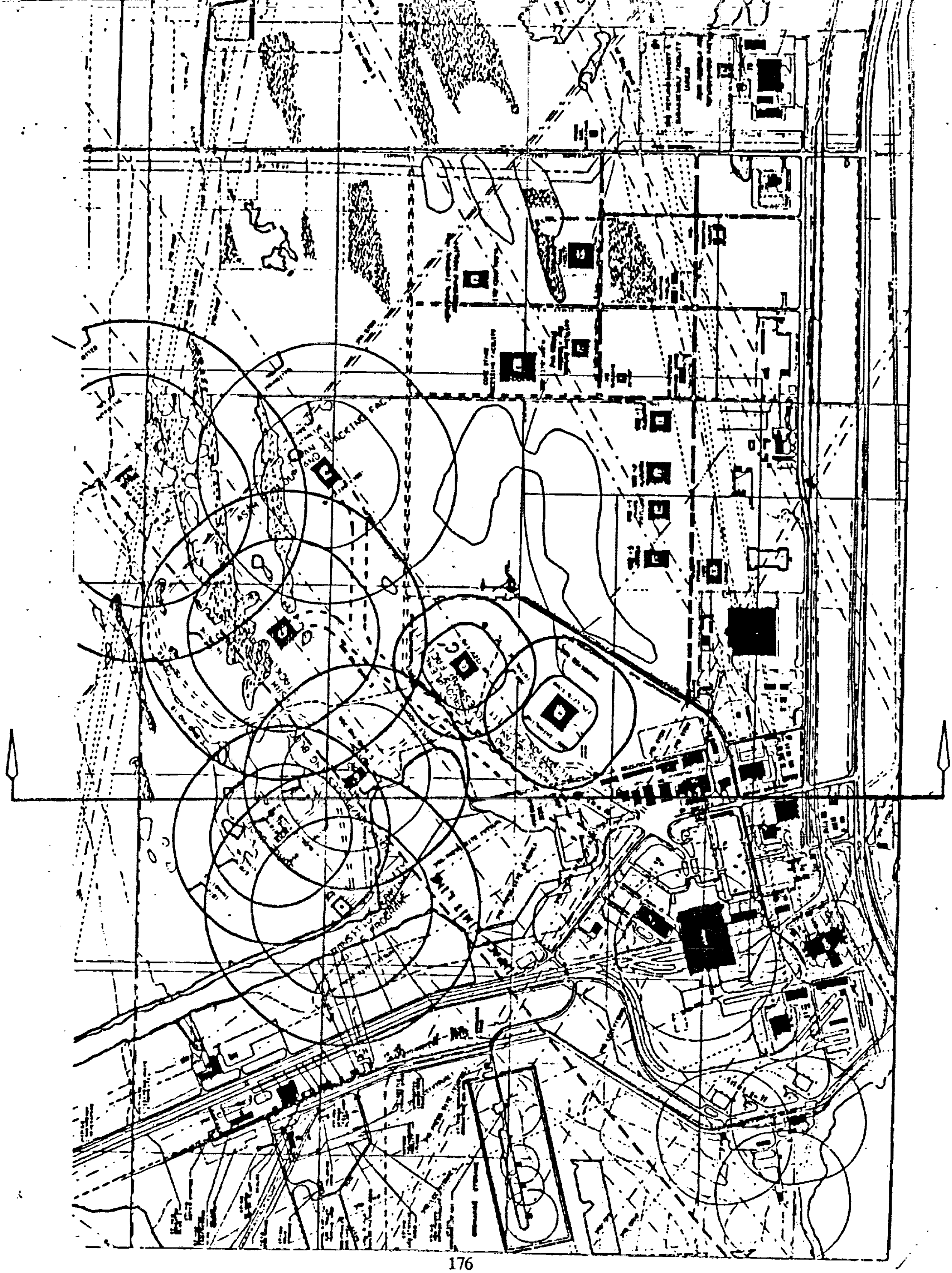

FIGURE 1. SUB-AREA OF 39 DISTRIBUTION SYSTEM UNDER STUDY

One of the four main transformers at C-5 substation is reserve. This leaves normal operating capacity of 30 MVA in the distribution system. The demand is approximately 98 percent of the rated normal operation capacity at the present but substantially below the maximum capacity.

Two feeders (FDR 605 and FDR 616) out of this substation supply electric power to the sub-area of interest. FDR 605 supplies power to the facilities in the sub-area under discussion through load break switches LBS 731, LBS 732, LBS 710, and LBS 709. Utilization facilities in the sub-area which draw power from FDR 616 are connected to one of the following load break switches - LBS 717, LBS 716, LBS 715, LBS 714, LBS 713, LBS 712, LBS 711, LBS 708, and LBS 50. See Figure 2 for the single line diagram showing the distribution network in sub-area affected by the load reallocation plan. This area was carved out for the study to cover most of the proposed utilization facilities. It is also the sub-area of the LC-39 distribution zone that has room for future facilities siting. Figure 3 is a diagram of the sub-area showing present distribution system and the proposed facilities.

2.3 Capacity-Demand Status of Substation and Feeders Under Load Reallocation Plan

To estimate the loss of load probability (LOLP) it is necessary to determine the capacity-demand margin. In the case of the substation, judgement can be based on one of several margins depending on the required level of reliability. The margins range from normal operation rated capacity-demand margin to maximum available capacity-demand margin. For the feeders the margins of interest are the differences between rated ampacities and the maximum demand current. Tables 1 and 2 show the present capacity-demand conditions relevant to the study.

III. LOCATING THE NEW SUBSTATION AND THE LOAD REALLOCATION PLAN

3.1 Optimal Location for the New Substation

The primary assumption for choosing a location for the new substation is that much of what necessitates the building of the substation are proposed facilities and anticipated growth. This is based on the reasoning that since the present capacity-demand margins (based on the normal operation rated capacity of C-5 substation) is virtually zero, it will be prudent to consider a new substation to support the proposed loads. By the same token, since there is no loss of load in the system at present, none of the present load needs to be transferred to another substation unless the transfer enhances system reliability while reducing cost and system losses. The basic variables for computing the location of the new substation are thus the distribution of the proposed utilization facilities and the area of greatest likelihood for future growth.

The underlining-philosphy is to determine a location for the proposed substation P-LC-39 that will result in minimum investment cost and system losses. If we assume that the construction and equipment costs are fixed (not dependent on location) then investment cost becomes a function of cable length L. Thus the problem of minimizing investment cost reduces to minimizing feeder length. A simple minimal path algorithm is suitable for this purpose, [1]. This is shown in paragraph 3.1.1

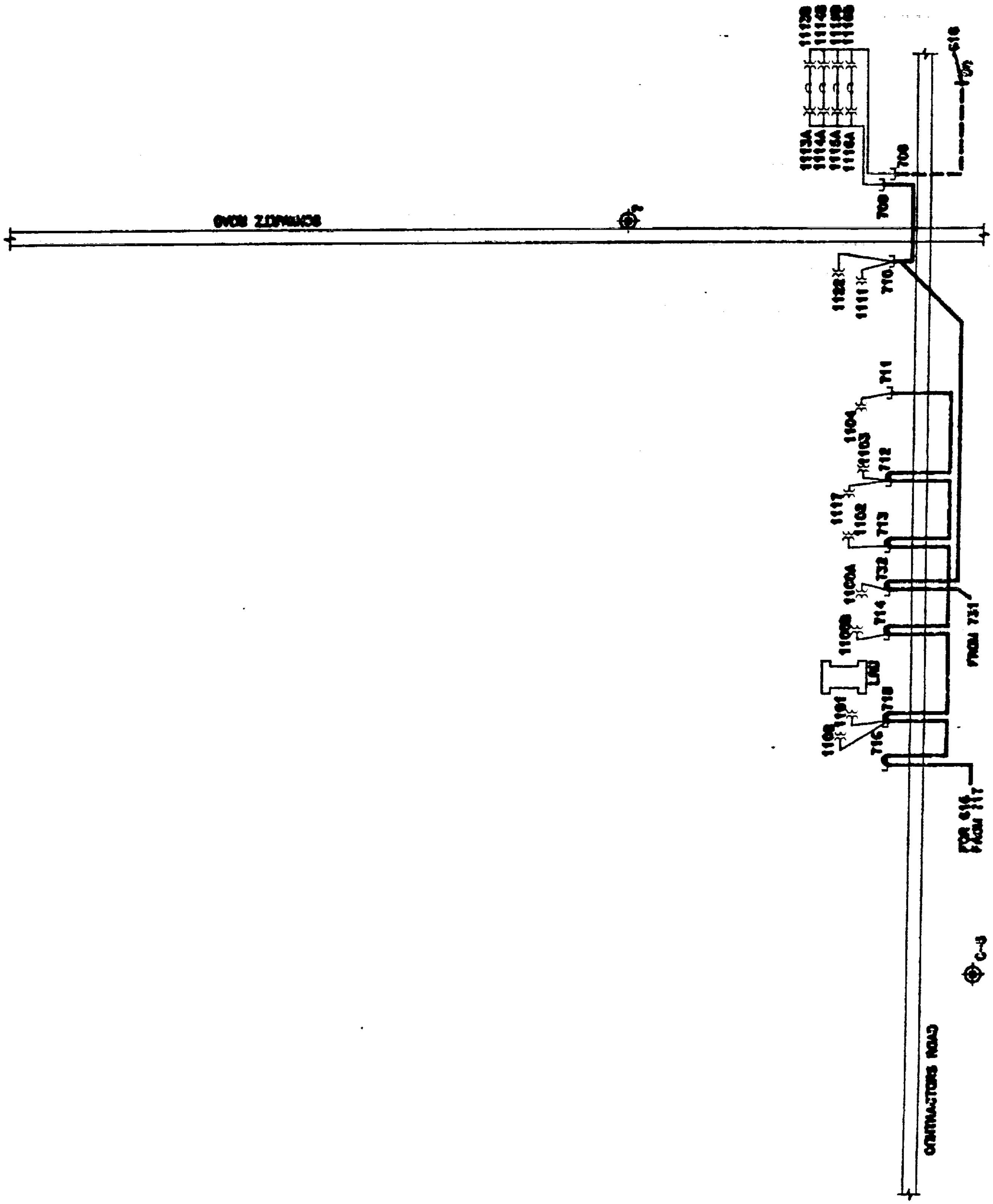

FIGURE 2. THE ELECTRIC POWER DISTRIBUTION NETWORK IN AREA UNDER STUDY

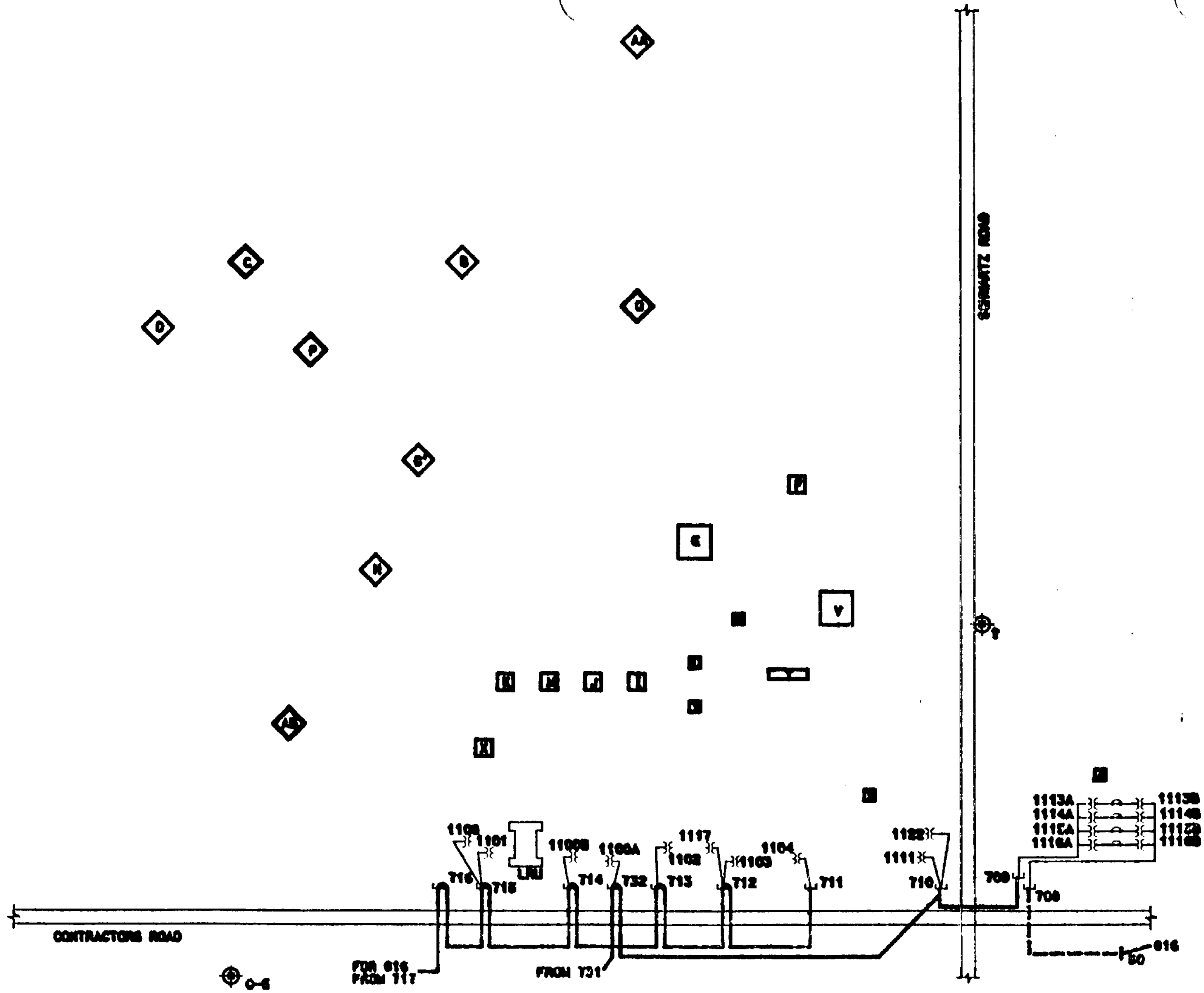

FIGURE 3. SHORT TERM PROPOSED FACILITIES AND PRESENT ELECTRIC SUPPLY NETWORK IN SUB-AREA

TABLE 1

C-5 SUBSTATION CAPACITY- LOAD MARGIN INFORMATION 1990

	CAPACITY (MVA)	LOAD (MVA)		MARGIN		
		CONNECTED	DEMAND	CAPACITY-CONNECTED (MVA)	CAPACITY-DEMAND MVA	%
55^{0} C, NO FAN	30.0	189.168	29.4	-159.168	0.6	2.0
65^{0} C, NO FAN	33.6	189.168	29.4	-155.568	3.6	10.7
55^{0} C, FAN COOLING	37.5	189.168	29.4	-151.668	8.1	21.6
65^{0} C, FAN COOLING	42.0	189.168	29.4	-147.168	12.6	3.0

The ratio of peak load to connected load is 15.54 percent which indicates that the capacity-connected load margin is not a good measure of system reliability. An overwhelming percentage of the connected load does not draw power simultaneously.

TABLE 2

AMPACITY-DEMAND MARGINS FOR FEEDERS UNDER LOAD REALLOCATION

FDR #	CONDUCTOR AMPACITY (AMPS)	DEMAND* (AMPS)	MARGIN AMPS	MARGIN %
605	307	120	187	60.9
616	280	180	100	35.7

*These are the maximum demand (peak values) for the year 1990.
(Available data at time of study, July 1990.)

If optimal conditions are attained by all the new loads being connected to P-LC-39 and the integrity of the present system preserved, then the minimum investment cost scheme will also produce a minimum system loss. However, if the location of P-LC-39 as obtained by the minimum cost algorithm (based on the proposed loads) results in a possible load reallocation, then the minimum power loss algorithm must be introduced. Indeed this may result in a shift in the position of P-LC-39, i.e., the minimum cost algorithm is used again to determine the final and optimal location of P-LC-39 based on the reallocation plan and the minimum power loss scheme. The minimum power loss algorithm is discussed in paragraph 3.1.2

3.1.1 The Minimum Cost Algorithm

With reference to figure 4. which shows the distribution of the proposed loads, define two sets:

S = {Connected Nodes}

$\bar{S}$ = {Unconnected Nodes} = {A, B, C, V, W, T, N, F, E, C', I, J, M, K, X, H, AA, D, U, Y, AB, P, LRU, O}

The problem is to determine the branches that will join all the nodes (load points) in $\bar{S}$ to form a network S, such that the sum of the lengths of the chosen branches is minimized. The process is a sequence of transitions of the elements (nodes) in $\bar{S}$ to S such that the distance i between elements i + 1 and any element in S is a minimum for i = 1, 2, 3, ...N, where N is the number of proposed load points in $\bar{S}$. The starting point is arbitrary. Let D be the starting node. The sets S and $\bar{S}$ now become:

S = {D}

$\bar{S}$ = {A, B, C, V, W, T, N, F, E, C', I, J, K, X, H, AA, U, Y, AB, P, LRU, O}.

Now compare the distances between D and the nodes in $\bar{S}$. The shortest distance is between D and C. Thus the sets S and $\bar{S}$ now become S = {D, C},$\bar{S}$ = {A, B, V, W, T, N, F, E, C', I, J, K, X, H, AA, U, Y, AB, P, LRU, O}. Now connect D to C and compare the distances from all the nodes in $\bar{S}$ to all the nodes in S. We select a node in $\bar{S}$ closest to a node in S. This node is P. Consequently, S = {D, C, P,}, $\bar{S}$ = {A , B, V, W, T, N, F, E, C', I, J, K, X, H, AA, U, AB, LRU, O}. P is connected to C (shortest link).

This procedure is continued until all load points are connected, i.e.:

S = {A, B, C, V, W, T, N, F, E, C', I, J, K, M, X, H, AA, D, U, Y, AB, P, LRU, O}.

$\bar{S} = \phi$

The number of iterations is N-1 where N is the number of proposed load points. The minimum spanning tree is shown in figure 5. If the proposed substation P-LC-39 is located on any of the branches it will result in minimum feeder cost. It should be noted that unlike in traditional application of minimum path algorithm, here a loop is allowable, but only if there

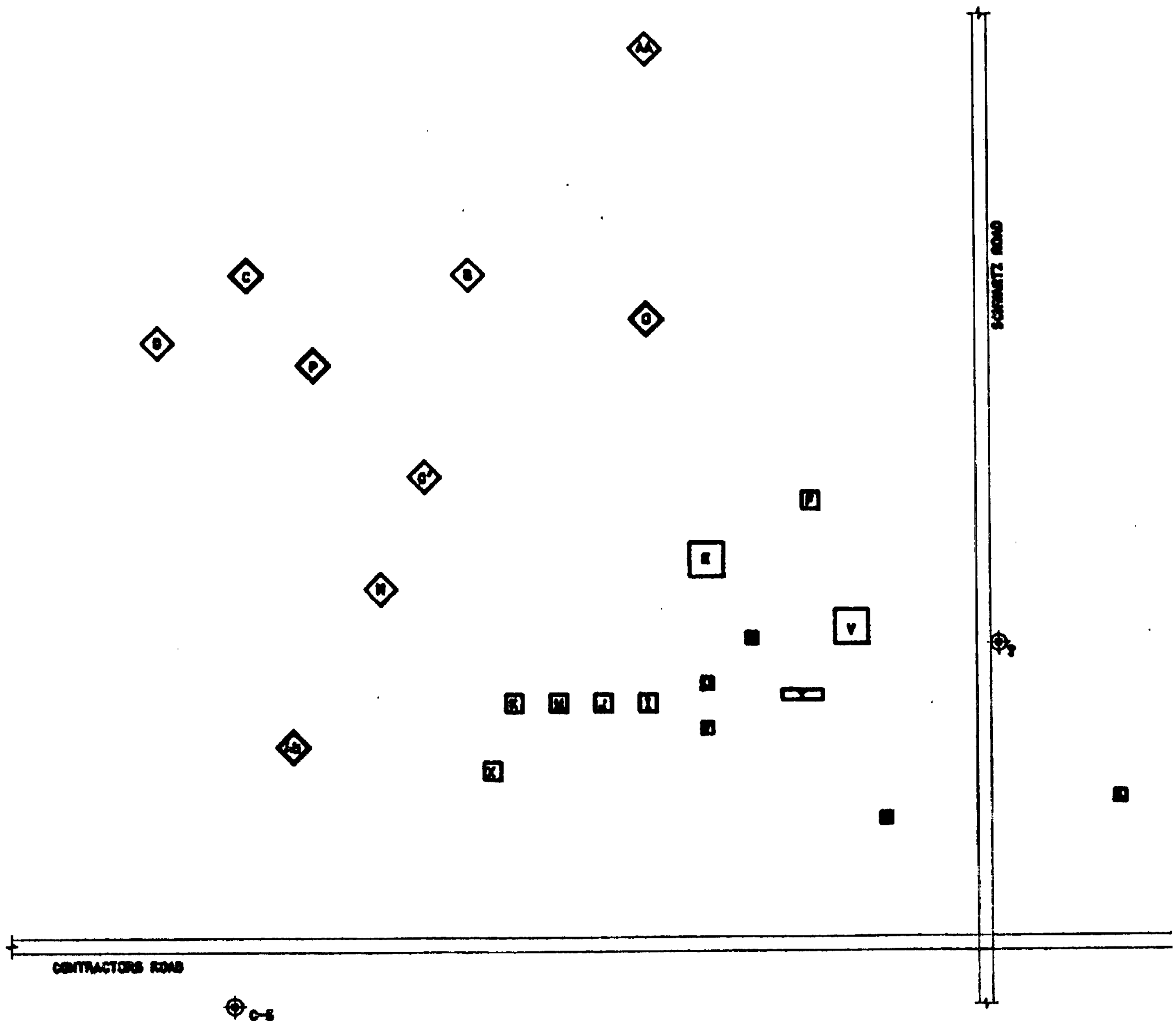

FIGURE 4(a). THE DISTRIBUTION OF PROPOSED UTILIZATION FACILITIES

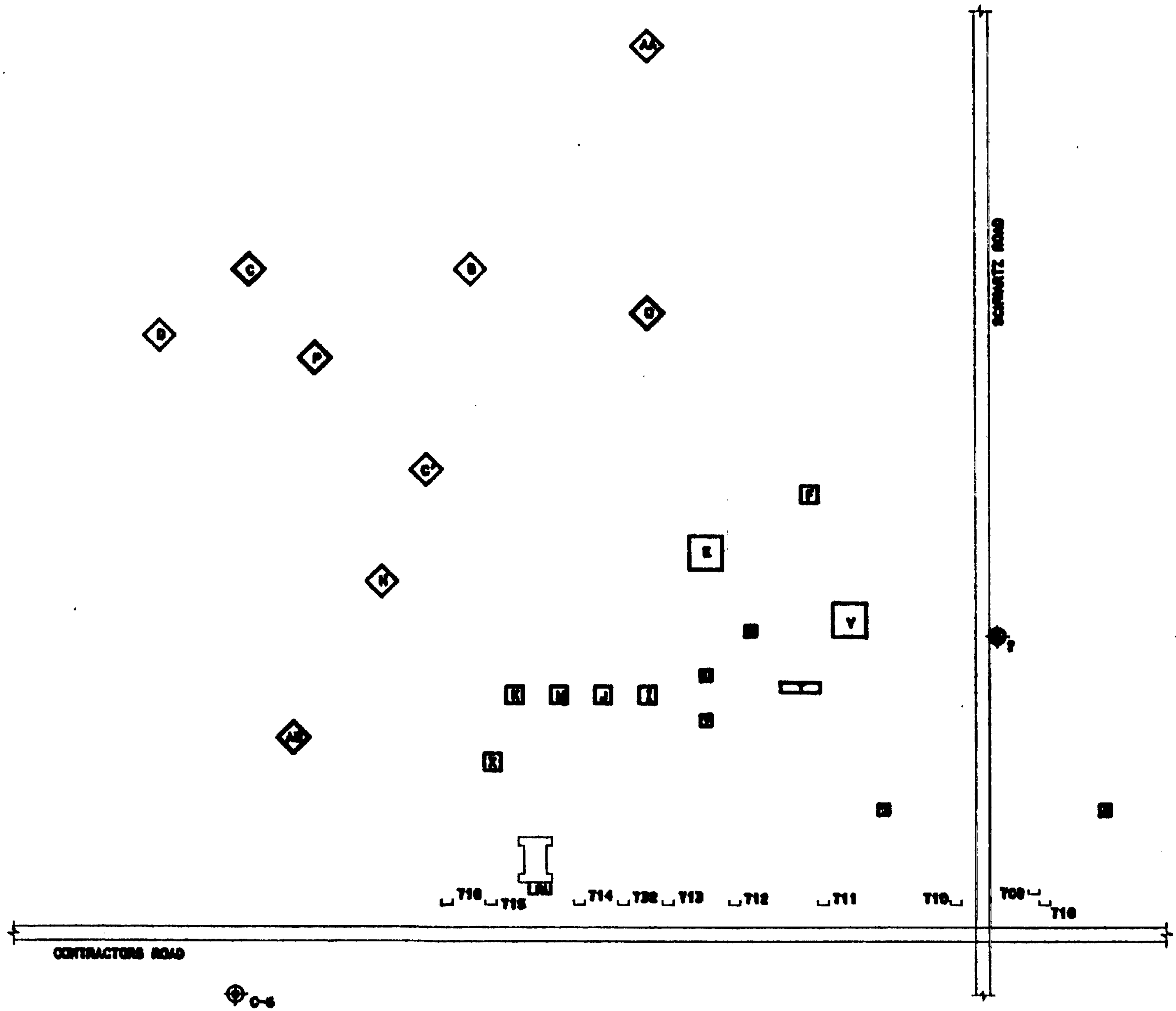

FIGURE 4(b). THE DISTRIBUTION OF PROPOSED FACILITIES AND PRESENT ELECTRIC LOAD POINTS

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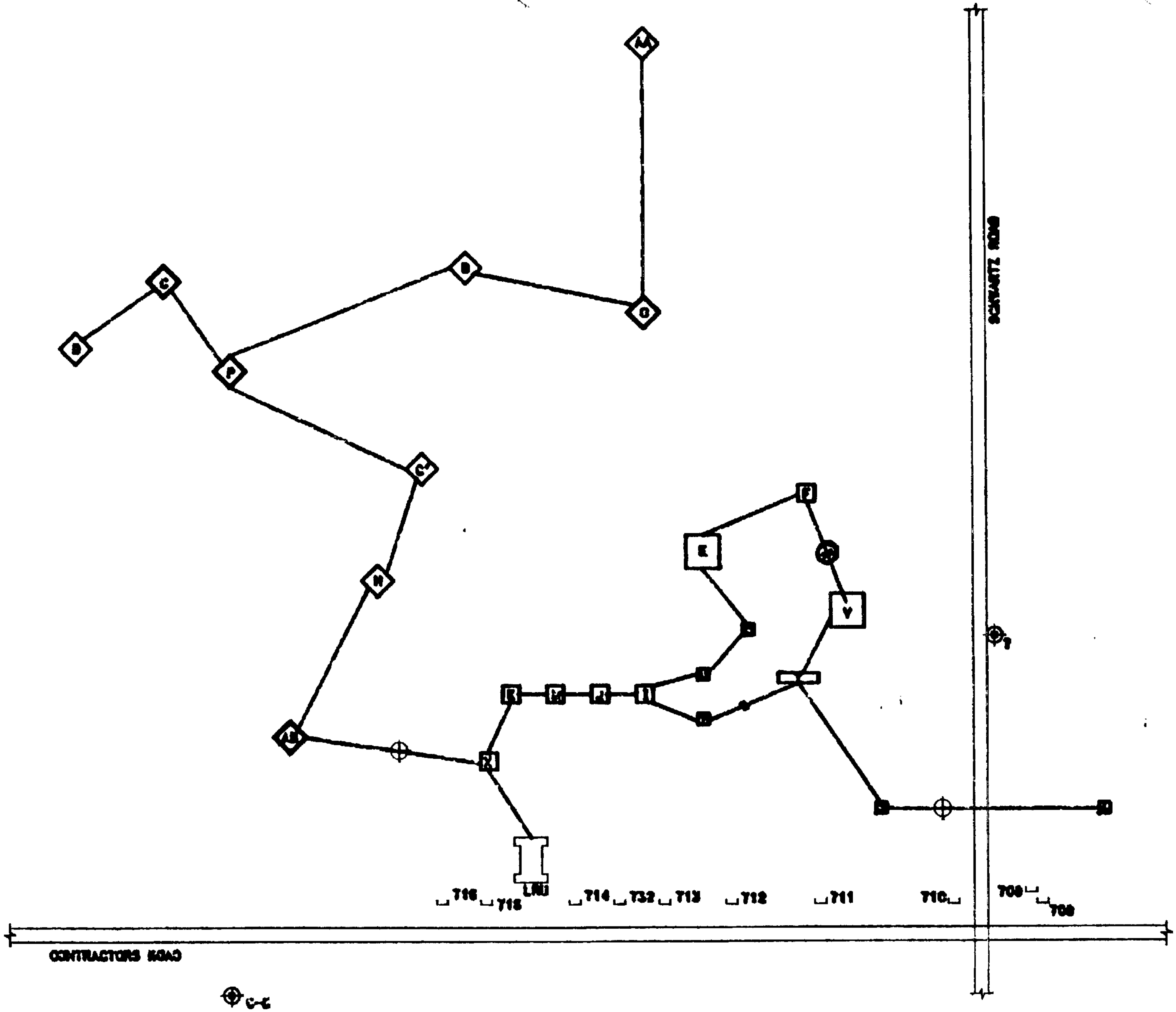

FIGURE 5. MINIMUM LENGTH NETWORK FOR CONNECTING ALL PROPOSED LOADS

is a tie. If this happens the equal links should be marked. Usually one of them will be eliminated or used to tie two feeders for switching purposes.

3.1.2 Load Reallocation and the Minimum Loss Algorithm

The power loss of a feeder is given by:

$$\text{Loss} = I^2R \qquad (1)$$

Where

I = the demand in amps

R = the resistance.

Since I, the current drawn by the loads is fixed for a given set of loads, loss can only be reduced by a reduction in R. But:

$$R = \frac{\rho L}{A} \qquad (2)$$

Where A, the cross sectional area and ρ the resistivity of the conductor are constant for a given feeder. Hence a reduction in R and consequently a reduction in feeder loss can be achieved by a reduction in the feeder length L. This means that to achieve minimum system loss, system feeder lengths must be minimum or the load reallocation plan must insist that loads be connected to sources closest to them. Thus the minimum loss algorithm is essentially the load allocation algorithm.

Having determined a location for the new substation, P-LC-39, the load reallocation algorithm is as follows:

With center P-LC-39 describe a circle radius r_1 in the load field. With center C-5, describe a circle of same radius r_1 in the load field. With these two centers, describe circles of equal radii r_2, r_3, r_4---. The number of pairs of circles depends on engineering judgement based on the load distribution. Similarly, spacing of the circles $r = r_{i+1} - r_i$ is arbitrarily chosen due to the load distribution. Label the circles, see figure 6. Circles with center P-LC-39 are labeled P_1, P_2, P_3... in order of increasing radius. Circles with center C-5 are labeled C_1, C_2, C_3-- in order of increasing radii. Compare the load points with respect to the circles and the load allocation rule is:

Assign Load Point X to P-LC-39

if $X \in P_i$ and $X \notin C_i$, $i = 1, 2, 3$---

Assign Load Point X to C-5

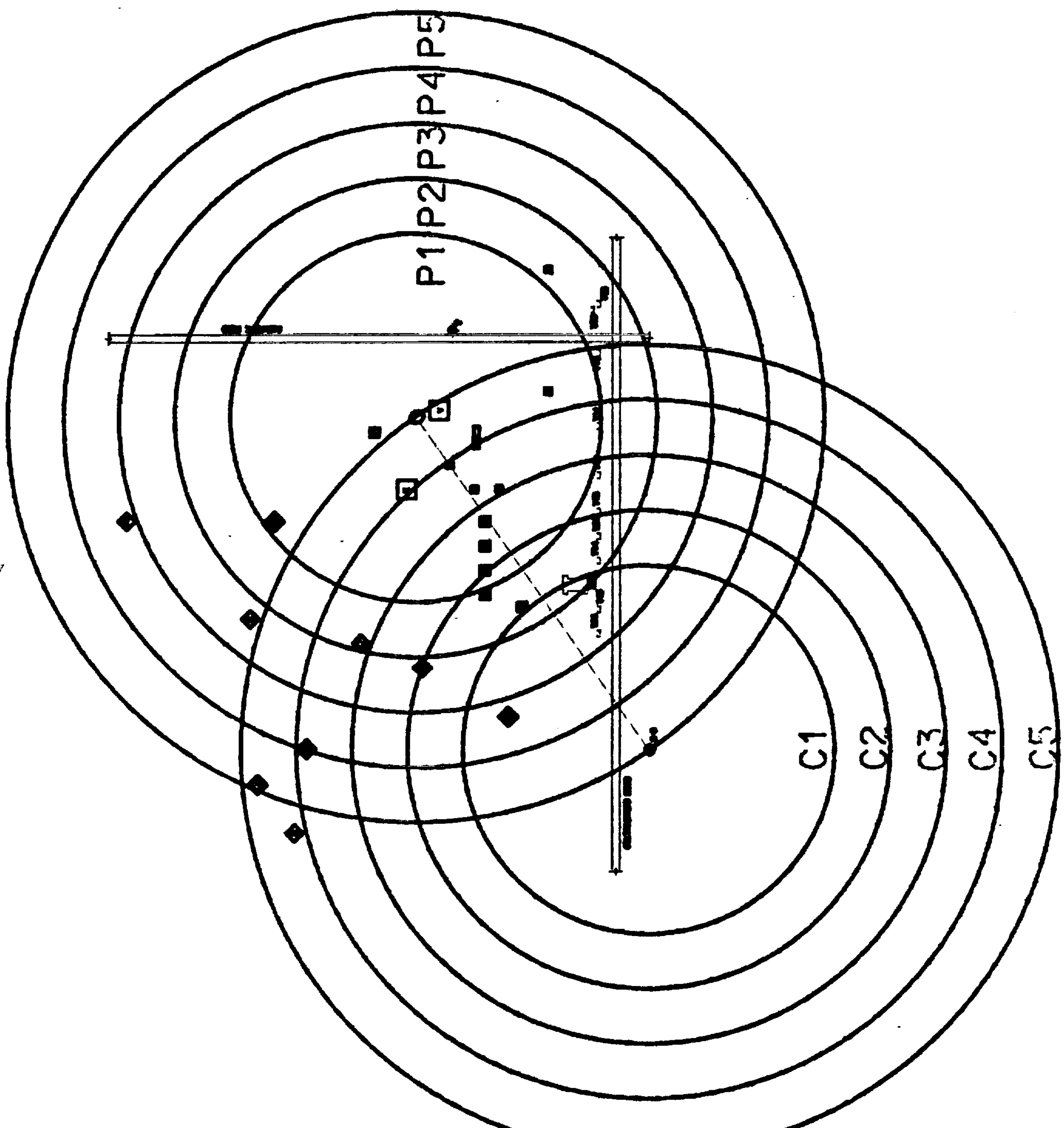

FIGURE 6. LOAD ALLOCATION CHART

if $X \in C_i$ and $X \notin P_i$.

It must be noted that the application of this rule is subject to some heuristic rules set by the system management. Examples of such rules are given in section 3.2. Also, if $X \in \{C_i \cap P_i\}$ assignment is arbitrary subject to some heuristic rules.

Using this load allocation plan feeders FDR 616 and FDR 605 are relieved of 5.175 MVA and 5.925 MVA, respectively, from the existing load while substation C-5 picks up 10.7 MVA of the proposed load. (See Table 3.) It can be observed that the effectiveness of this plan has resulted in a relief on the two feeders in C-5 which at the present suffer the highest demand/ampacity ratios (highest load factors).

3.1.3 The Optimal System

The algorithm just described produces a minimum power loss load allocation. To further optimize the system each substation distribution network must be connected subject to some rules.

3.1.3a The Proposed Substation P-LC-39 Distribution Network

Now that loads have been assigned to the proposed substation, the algorithm of Section 3.1.1 is used to determine the final set of points (links) on which P-LC-39 can be located. This time the initial set $\overline{S}$ (iteration 0) shall consist of all the loads (present and proposed) that were allocated to P-LC-39 by the algorithm of section 3.1.2. This recursive relationship between the two algorithms guarantees a simultaneous minimization of investment cost and system losses in the load allocation scheme. The minimum spanning tree for the final selection of P-LC-39 location is shown in Figure 7. It may be noted that this tree coincides with that of Figure 5, thus, the recursive process terminates.

After the load reallocation and the final selection of P-LC-39 location, the minimum power loss algorithm proceeds thus for P-LC-39:

STEP 1: Connect the load points in P_1 to P-LC-39 forming new feeders for P-LC-39. These feeders should not violate the constraints set by management. Otherwise, another location must be chosen for P-LC-39 and this step repeated.

STEP 2: Connect each load point in P_2, but not in C_2 to any one of the load points in P_1.

STEP 3: Repeat step 2 for i = 3, 4, ..., connecting load points in P_i to any load point in P_{i-1}, provided other constraints are not violated.

3.1.3b. Connection of Load Reallocated to C-5

A rule that must be followed for reaching a minimum power loss and investment cost load allocation plan for C-5 is:

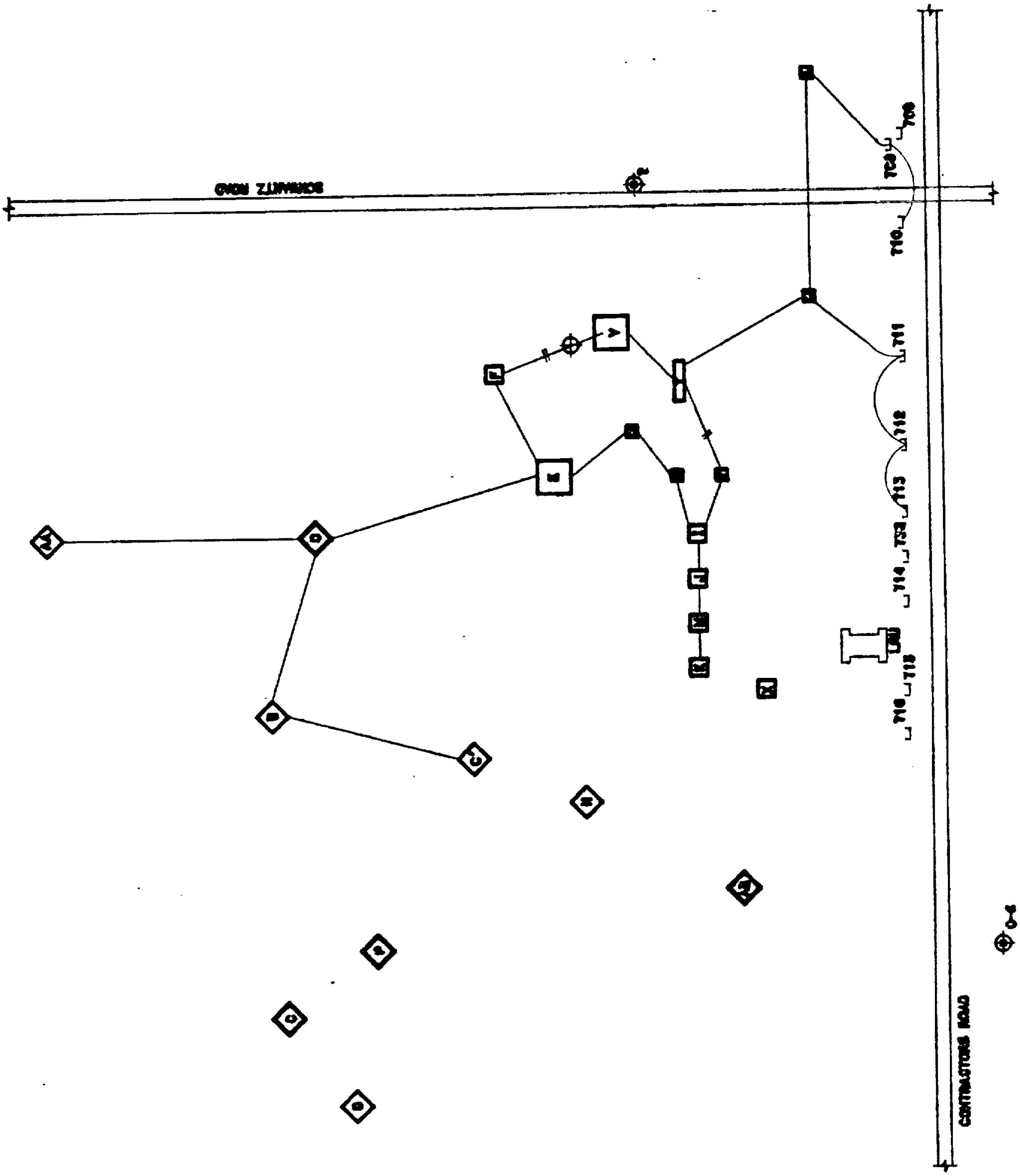

FIGURE 7. THE OPTIMAL LOCATION SET FOR P-LC-39

TABLE 3

LOAD POINTS AFFECTED BY LOAD RELOCATION

A. TRANSFER FROM C-5 TO P-LC-39

FDR#	LBS #	USS #	SIZE (KVA)
605	709	1113A'	2000
		1114A	750
		1115A	1000
		1116A	300
	710	1111	150
		1122	225
	732	1100A	1500
616	708	1113B	2000
		1114B	750
		1115B	1000
		1116B	300
	711	1104	75
	712	1103	750
		1117	225
	713	1102	75

Total transfer from C-5 = 11.1 MVA.

B. CONNECT TO C-5 FEEDERS

PROPOSED LOAD ID	ESTIMATED SIZE (KVA)
P	2000
C	300
D	200
H	3000
LRU	1000
X	200
AB	4000

Total new load to be connected to C-5 = 10.7 MVA, estimated value.

The load points which are connected to an existing feeder and fall within the same circle C_i must be connected in the load allocation plan. In addition to this rule, connection of load points in C_i to load points in C_{i-1} should also be followed subject to capacity constraints.

3.2 Heuristic Rules for Load Reallocation

The mathematical procedures outlined in section 3.1 result in an optimum system in an ideal world. The application of those rules, however, must be subject to some constraints which are determined by engineers based on their experience, environment, and required level of reliability. The following are examples of such constraints:

1. Constraints on Substations

   (a) The location of the new substation P-LC-39 is subject to (i) Environmental Constraints: These are the existence of wetland in the area and danger to wild life. From discussions with the environmental staff, it is noted that these constraints are relaxed for LC-39 area. (ii) Social constraints: The substations must be built not to interfere with planned streets and roads, or with probable area of facility location. There are indications from the real estate managers that this constraint is very soft particularly relative to the branches of the minimum spanning tree of figure 7.

   (b) It is the place of the system planners to determine the capacity of the new substation based on their need. It is also the system planners engineering judgement that sets the allowable demand/capacity ratio according as the level of reliability required. A typical rule is [2]: If the load of a substation is greater than 70% of its installed capacity, another substation is needed.

   (c) If the substation design does not tie the main transformers in parallel (connected to one bus) then the planners must set the allowable connected load/capacity ratio for a transformer. Under the same situation, the allowable number of feeders to a transformer should also be specified.

2. Constraints on Feeders

   (a) The load factor should not exceed a set value.

   (b) The maximum load (MVA) to be supported by a feeder should be specified.

   (c) The maximum number of load break switches to be connected to a load break switch should be specified.

   (d) An acceptable voltage regulation for each load break switch (or load point) must be specified.

The actual implementation of the load allocation feeder design, substation design, and load connections should take these rules into consideration while conforming with the guidelines of the algorithms of section 3.1

IV. RESULTS AND RECOMMENDATIONS

The main goals of this study are (a) to determine whether to build a new substation or expand the capacity of C-5; (b) to determine the best possible location(s) of the new substation if one should be built.

(a) The study concludes that a new substation should be built based on the following:

(1) There will be a reduction in system losses if this option is adopted and the load allocation scheme implemented.

Suppose all the proposed loads are to be connected to an expanded C-5 substation. Then in comparison to connecting them or some of them to a new P-LC-39 substation which is optimally located, the distance between C-5 and the furthest load AA is greater than the distance between P-LC-39 and any of the proposed loads. This implies that the minimum power loss chart for C-5 will consist of more zones (circles) than that of P-LC-39 to cover all the loads. From the discussions of section 3.1.3, it is obvious that power loss is proportional to the number of zones (concentric circles). Measurements show that the ratio of power losses for the two alternatives is 3.5:8.0 in favor of the new substation alternative. (See Figure 8.)

(2) The new substation option will result in savings in investment cost.

Suppose it is proposed to expand C-5 to accommodate all the new loads. Then new feeders must be added to connect those loads. A minimum length network for this purpose is shown in Figure 9. In comparison to Figure 7, this scheme uses (302-206) 96 more unit lengths of feeder. This alternative would thus cost more.

(3) In addition to the above deterministic criteria, other reasons for choosing the new substation alternative which are not readily quantifiable include:

a) Avoiding the mixture of new main transformers with twenty-six year old transformers. If new transformers with possibly different specifications are connected in parallel to the existing old transformers in C-5 it may create impedance mismatch problems, stability problems, and increase uncertainty in system reliability. The mixture will also create maintenance scheduling problems.

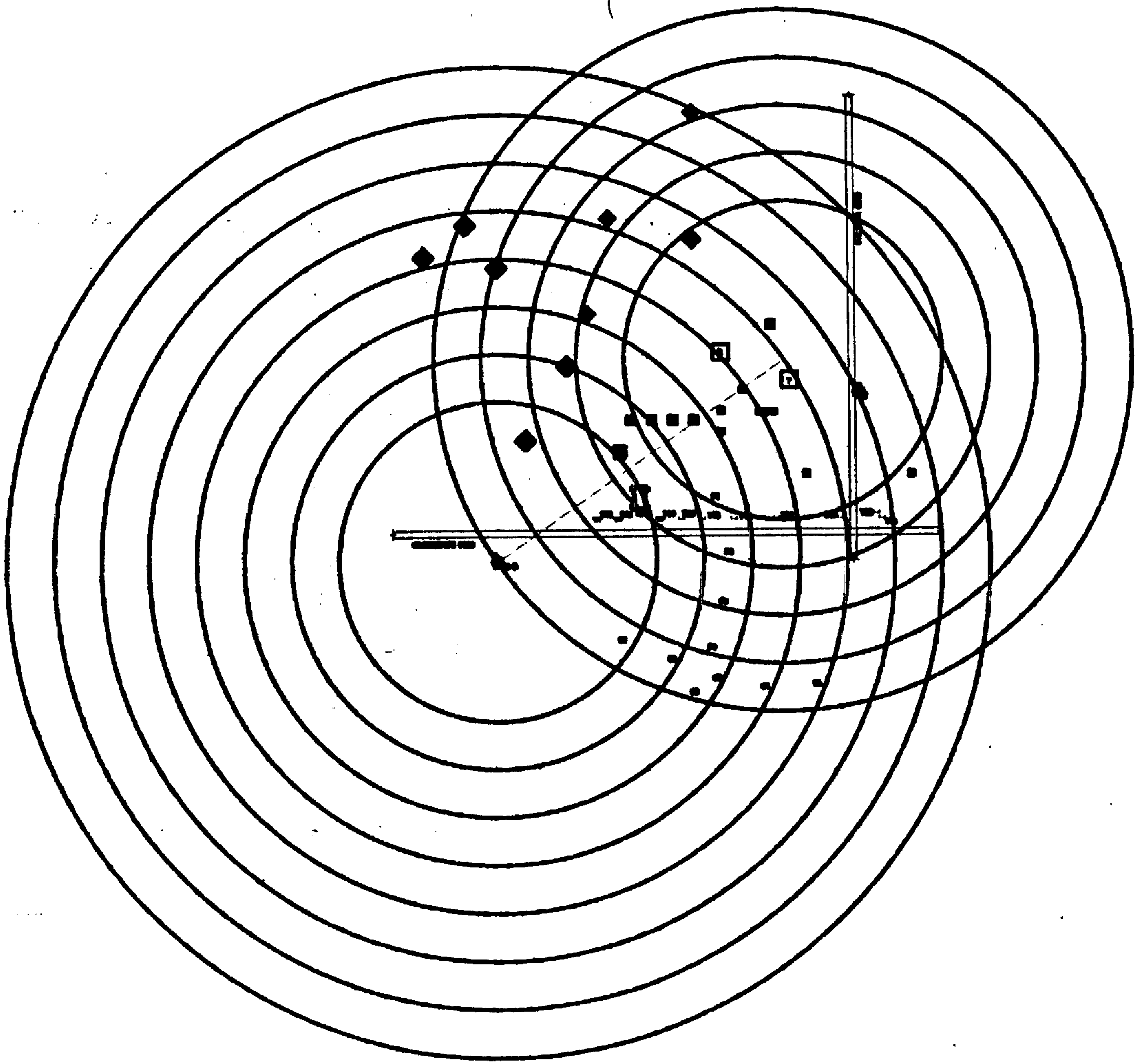

FIGURE 8. A COMPARISON OF THE MINIMUM-LOSS CHARTS FOR THE COMPETING ALTERNATIVES

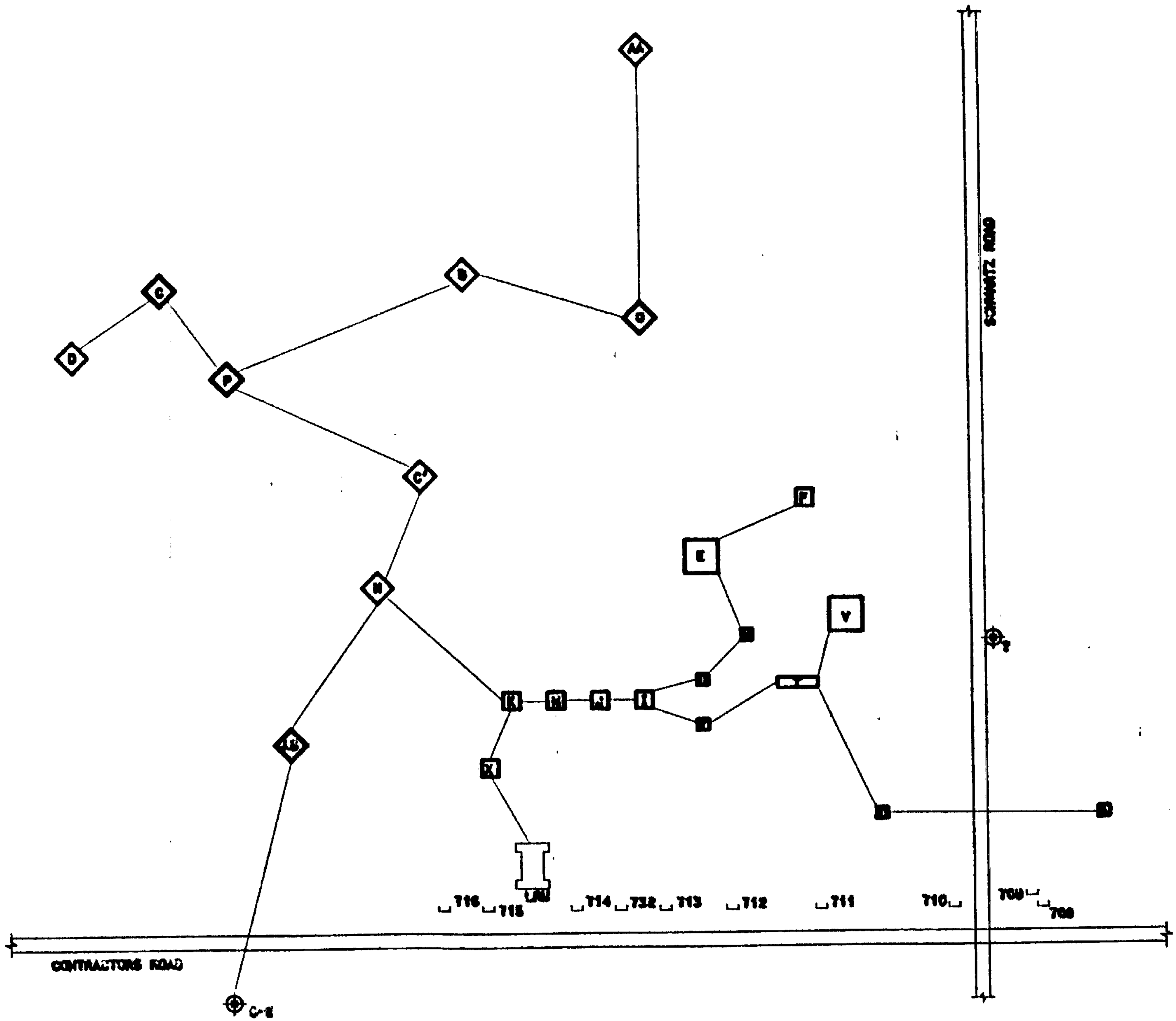

FIGURE 9. MINIMUM LENGTH NETWORK FOR CONNECTING ALL NEW LOADS TO C-5

b) Considering the area of greatest likelihood of growth, the new substation will result in greater long term savings.

c) System reliability will be enhanced by the construction of a new substation which can have an emergency assistance tie with the existing substation.

d) System studies will be much easier if the loads are divided into two substations.

V. CONCLUDING REMARKS

This study concludes that a new substation should be built to support the proposed loads and any future growth. The load reallocation of table 3 is based on the authors choice of the location of the new substation. (See Figure 7.) This choice is based on the fact that future growths are most likely to occur in the southeast portion of the area. Figures 5 and 7 show a set of points where the substation can be located. Any point on the links on the tree of Figure 7 will yield the same result. The case of locating the substation close to the transmission line should be irrelevant if the primary concern is to save cost to NASA-KSC. Transmission line is a delivery mechanism whereby the power supplier (FP&L) delivers power to its customers. One would then expect the cost of transmission to be borne by FP&L. More importantly, KSC power consumption is metered at its substations. This excludes the power losses in the transmission line. It is therefore more important to optimize P-LC-39 location with respect to distribution feeder lengths and losses in the feeders than with respect to its proximity to the transmission line. The actual size and location of the substation will depend on the system planners and designers. This note is intended to be a guide, if followed will result in a reliable system with desirable performance indices, and reduce cost.

REFERENCES

[1] Chan, J., and Y. Hsu; "An Expert System for Load Allocation in Distribution Expansion Planning," IEEE Trans Power Delivery, Vol. H, No 3., July 1989.

[2] Akoi, K., et al; "Normal State Optimal Load Allocation in Distribution Systems," IEEE Trans Power Delivery, Vol. 2, No. 1, 1987.